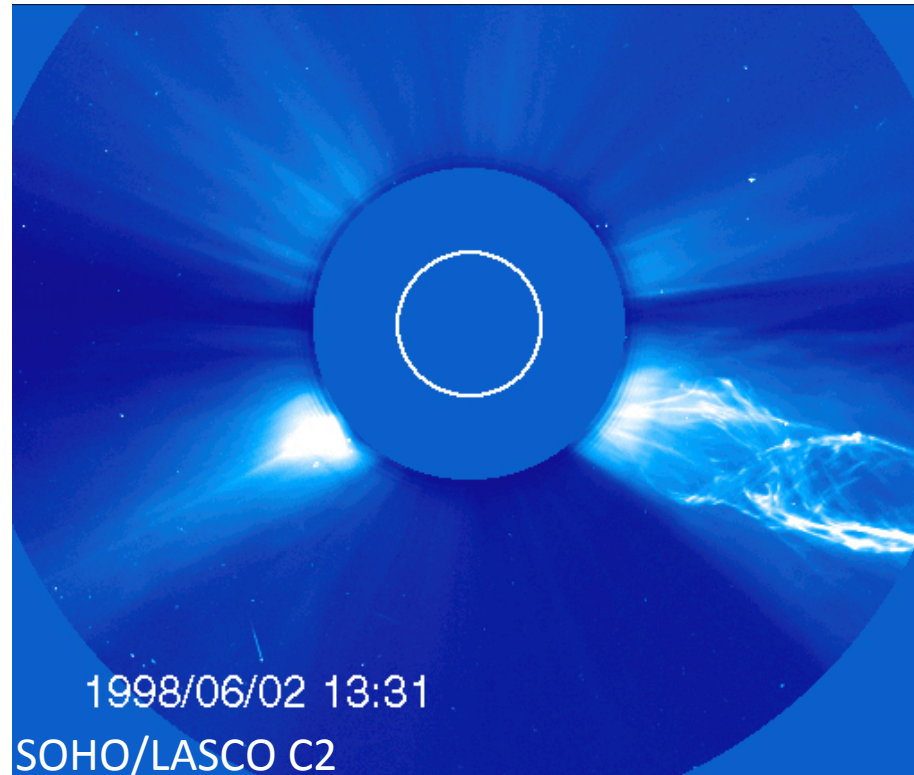


CME Analysis with StereoCAT for Space Weather: Part 1



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Barbara Thompson (NASA/GSFC) barbara.j.thompson@nasa.gov

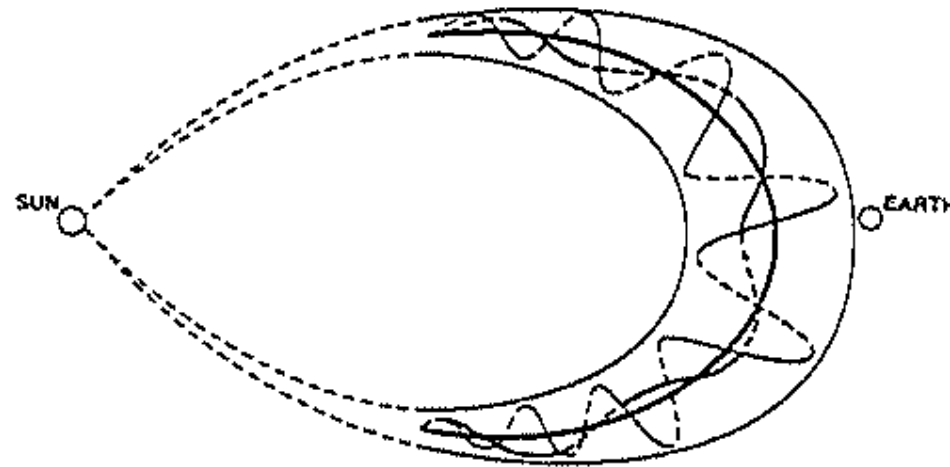
[SW REDI](#)

2014 June 3-13

Coronal Mass Ejections are important drivers of space weather activity.

Their shocks can accelerate particles (SEPs).

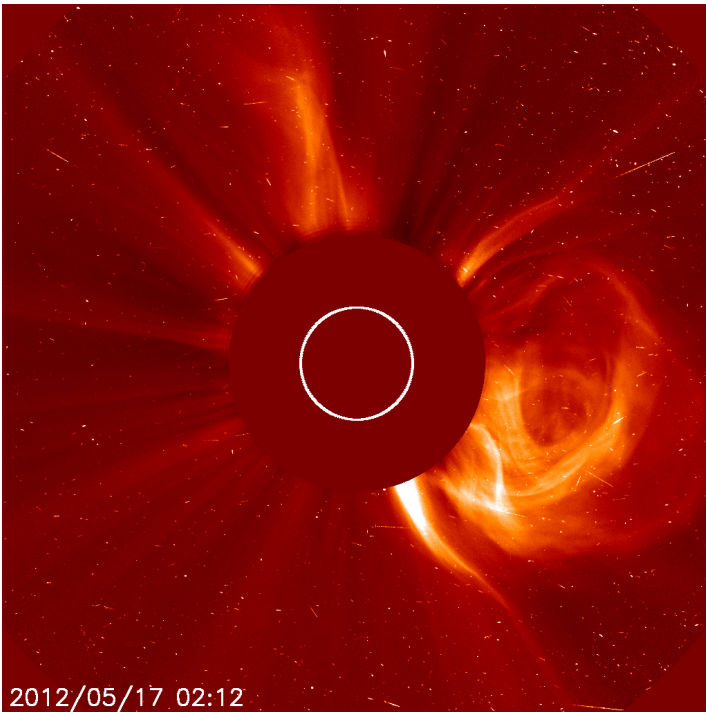
Earth directed CMEs (CMEs that propagate towards Earth's location) produce the majority of geomagnetic storms.



Purpose of this lesson: Learn how to measure the kinematic properties of CMEs (CME parameters) and determine their qualitative features.

Motivation: CME parameters are used as initial conditions of CME propagation models. These models are used to estimate the CME path and arrival time at various locations.

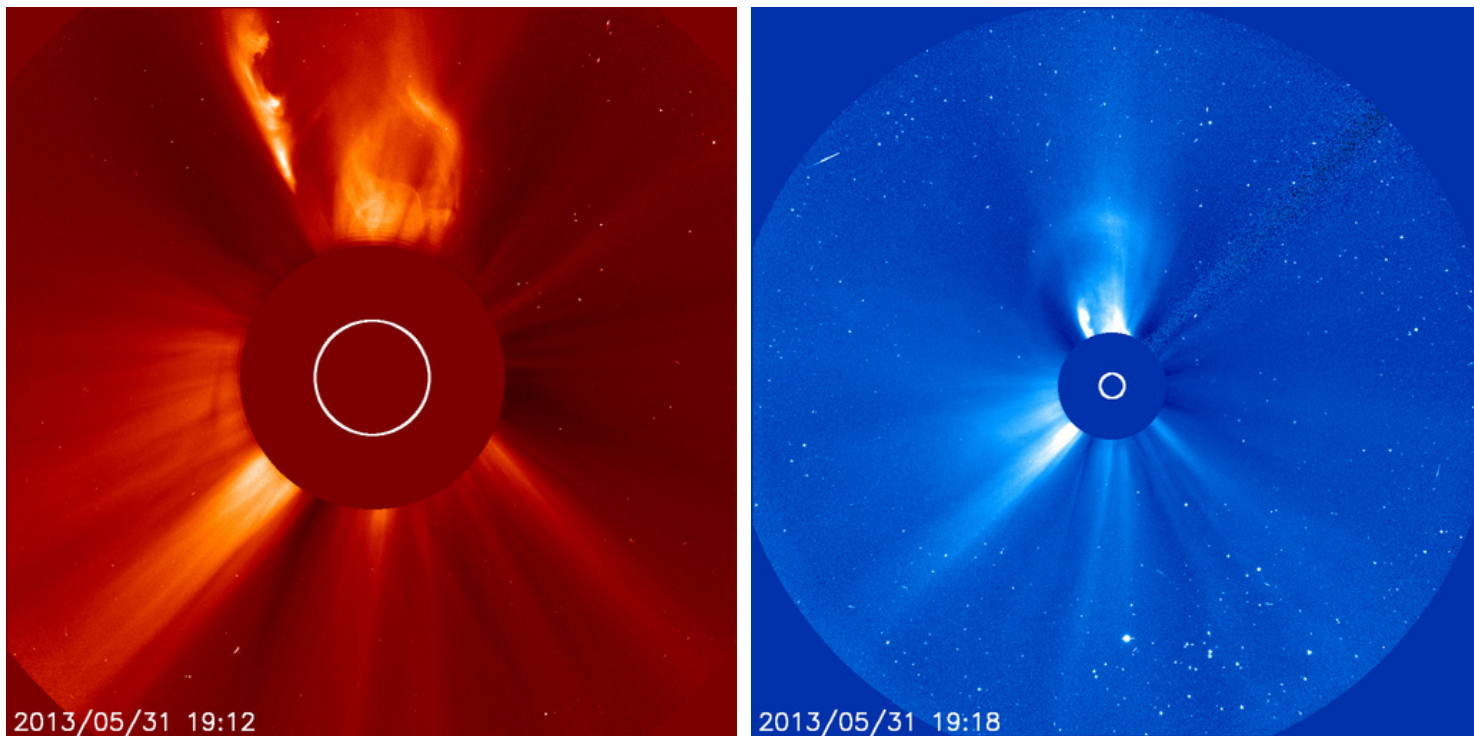
Coronal Mass Ejections



- Removal of magnetic field and mass from the solar corona – clouds of magnetized plasma
- $10^{12} - 10^{13}$ kg mass
- CMEs originate from closed magnetic field regions, such as active regions, filament regions.
- Appear as bright loops moving away from sun in **coronagraphs**

Coronagraphs block out the direct light of the Sun in order to view the faint corona.

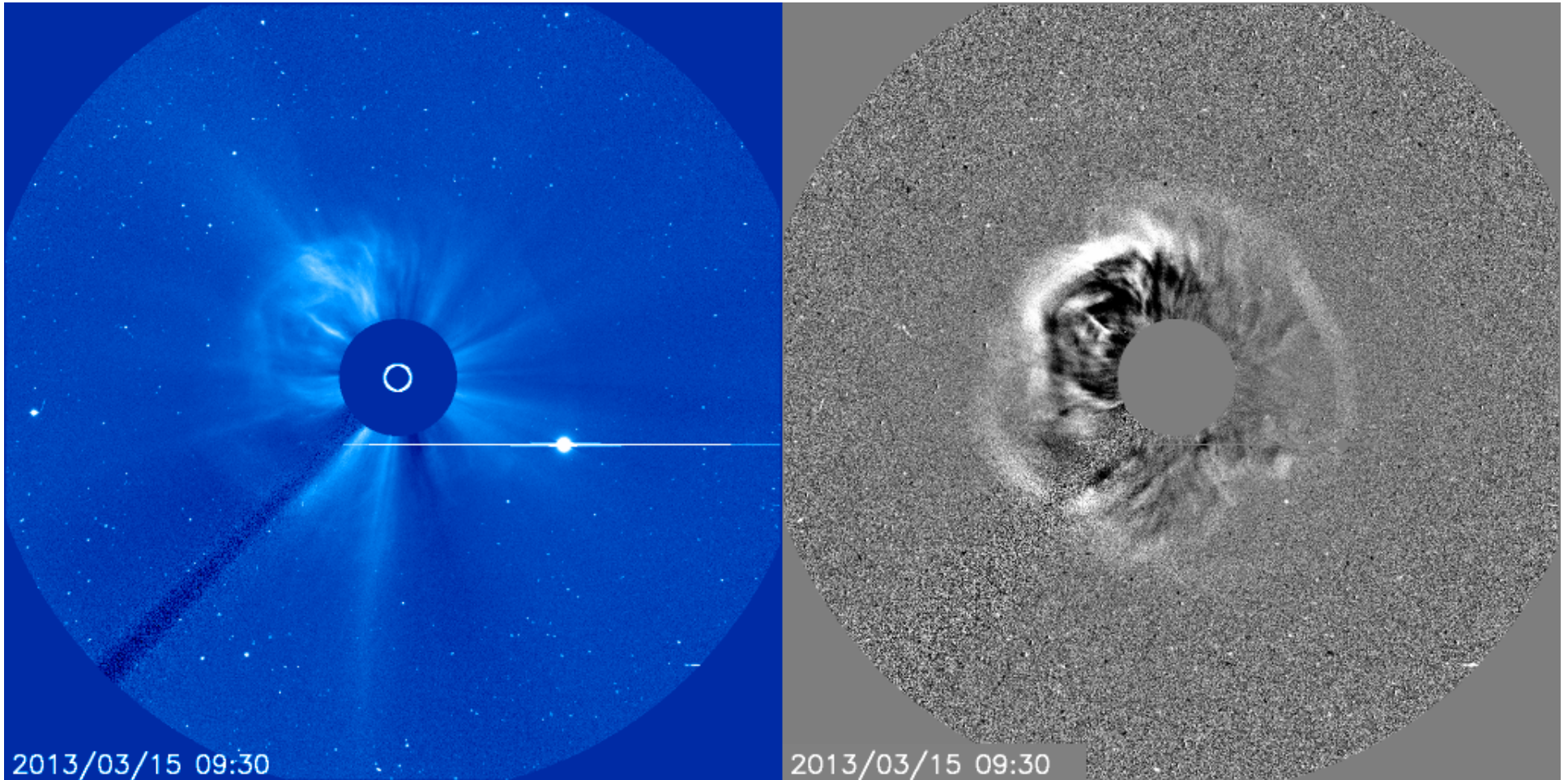
They are white light images, line of sight integrated scattered light from the Sun from the coronal electrons (**Thomson scattering**). You are seeing the CME projected onto the **plane of the sky**



The **plane of the sky** is the instrument image plane seen here

Example [movies](#)

Halo CMEs are CMEs that appear to surround the occulting disk of the coronagraph. The CME can originate from the front or back side of the Sun, and therefore are travelling either towards or away from the observer.

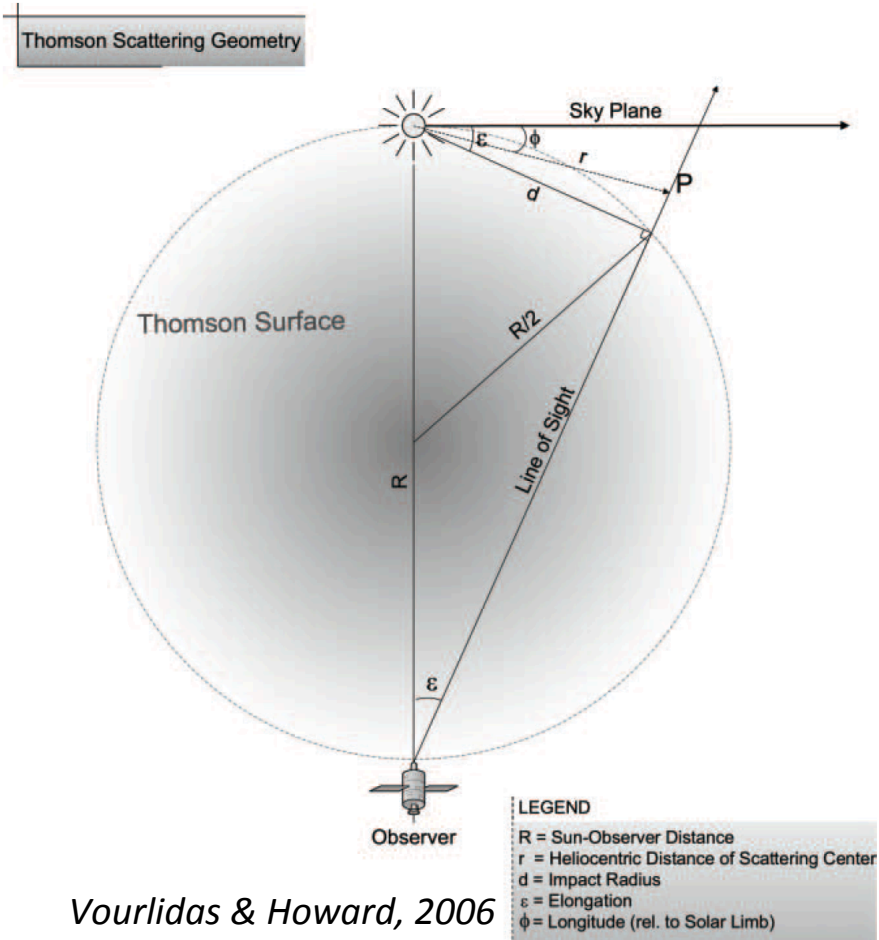


Due to scattering and projection, the CME sides or flanks are detected in these images

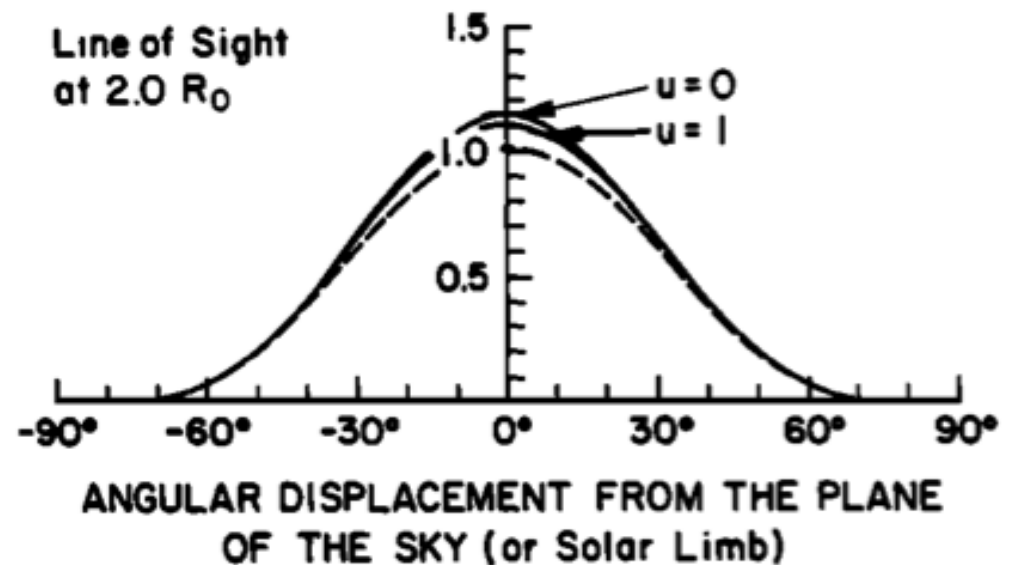
How CMEs appear in **coronagraphs** depend on projection effects and Thomson scattering amplitudes (*more on this in part 2*).

* In general, close to the Sun, CMEs which are far from the plane of sky are less visible, but the CME width should be considered.

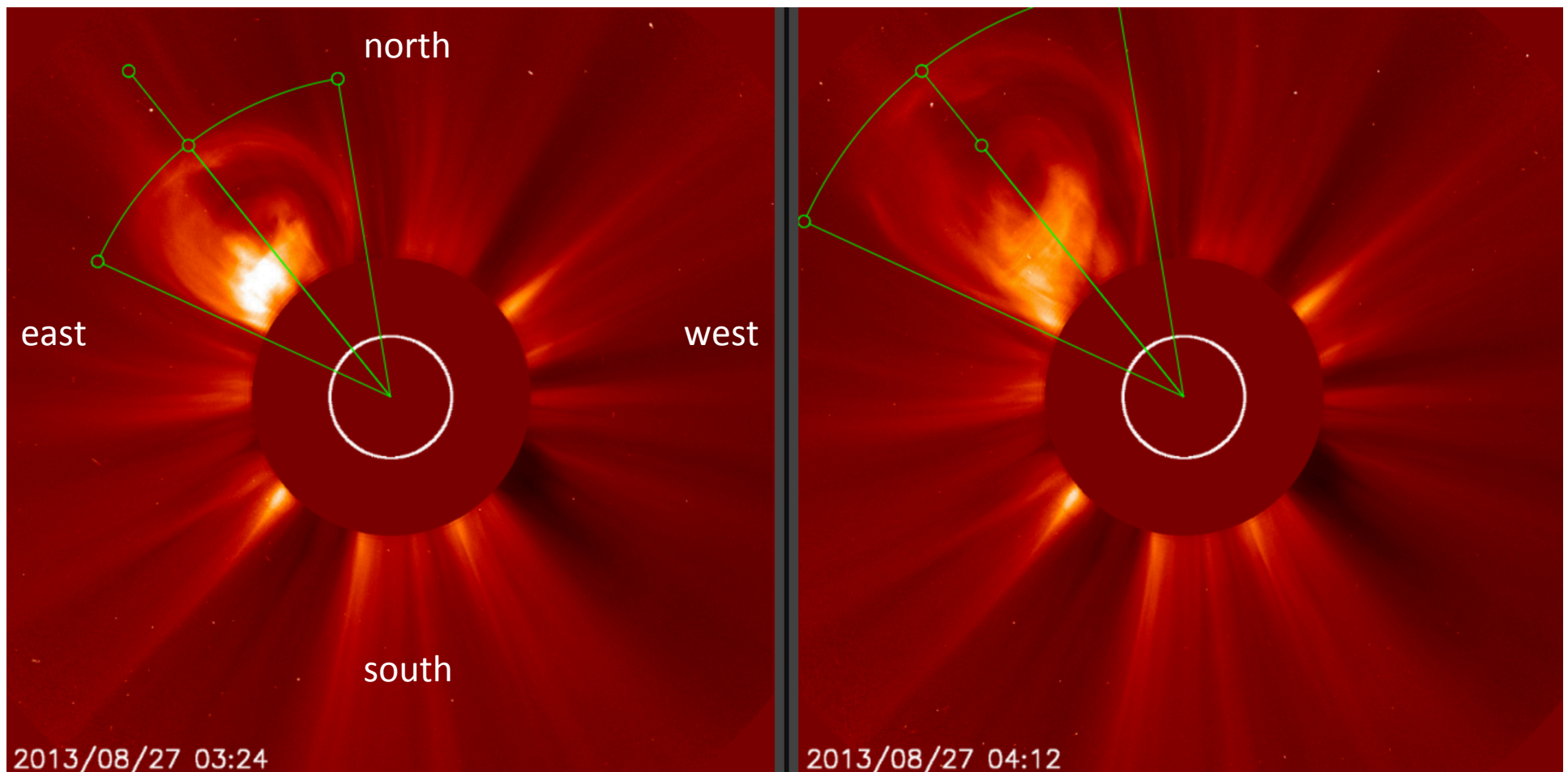
* The most brightness is visible near “Thomson surface”.



Scattering efficiency closer to the Sun (Hundhausen et al. 1993):

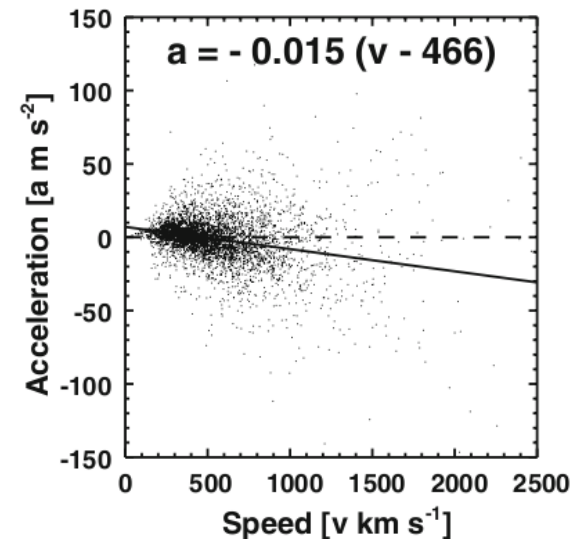
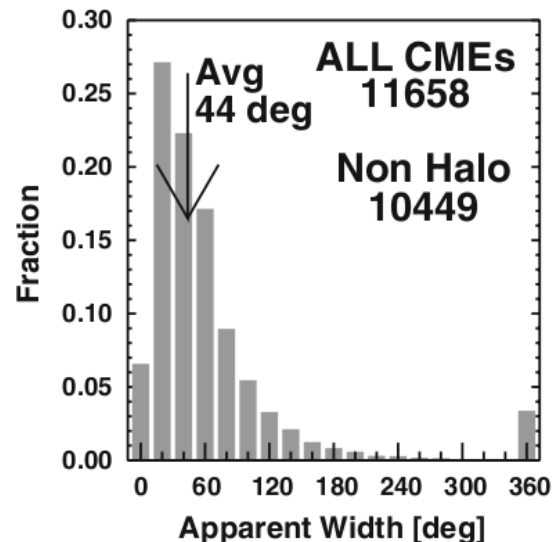
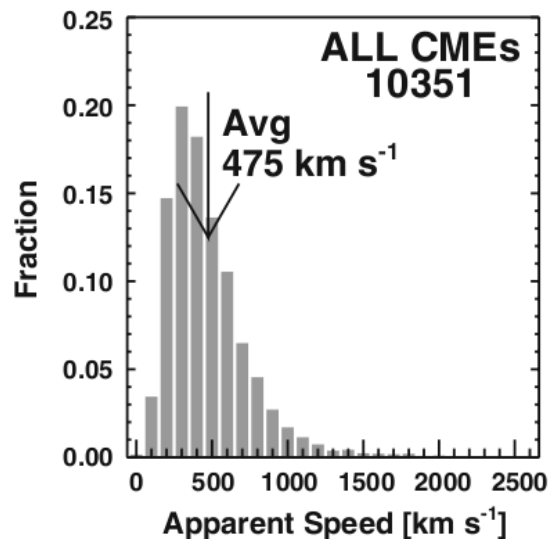


With **coronagraph** data you can measure the leading of the CME at different times. From this you can determine the “**plane-of-sky**” speed by measuring the position of the **leading edge** of the CME at two times. By using **coronagraphs** on various spacecraft, you can get a measurements of this projected speed from various viewpoints.



Coronal Mass Ejection Parameters

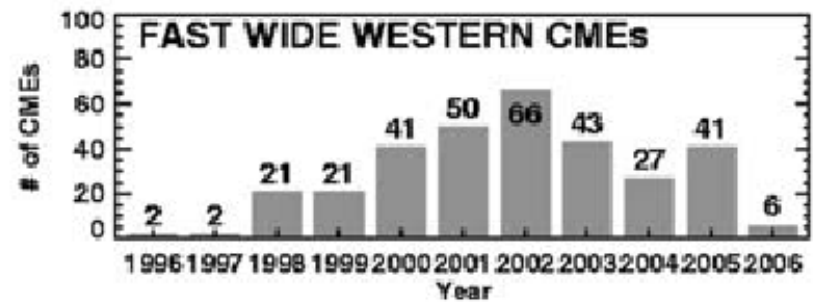
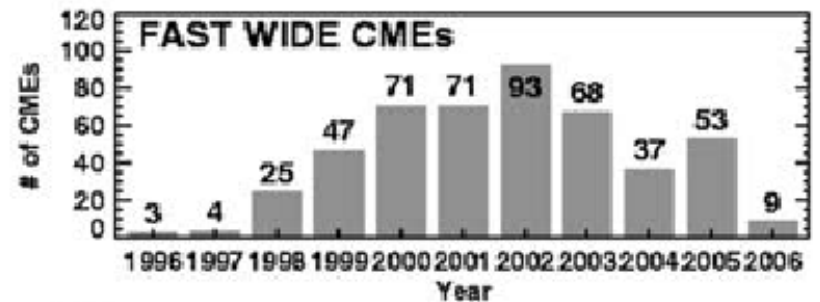
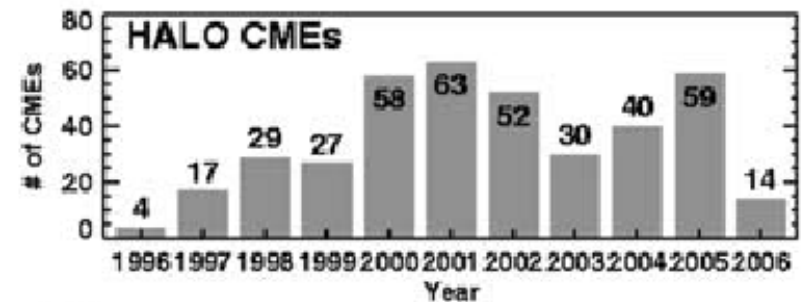
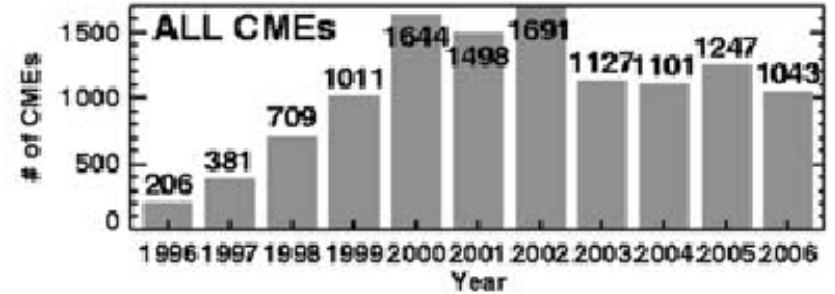
- Average speed ~ 475 km/s, width ~ 44 deg



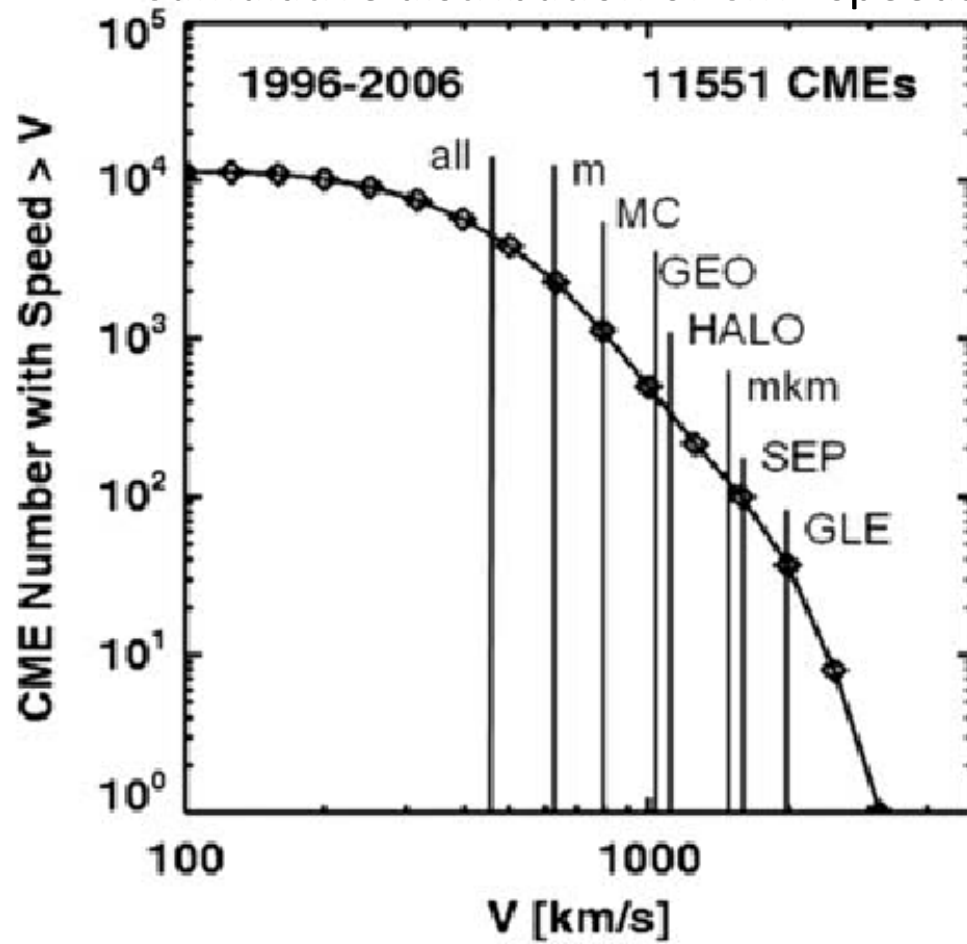
(Gopalswamy et al., 2010)

[SOHO LASCO CME Catalog](#)

Annual number of different CMEs

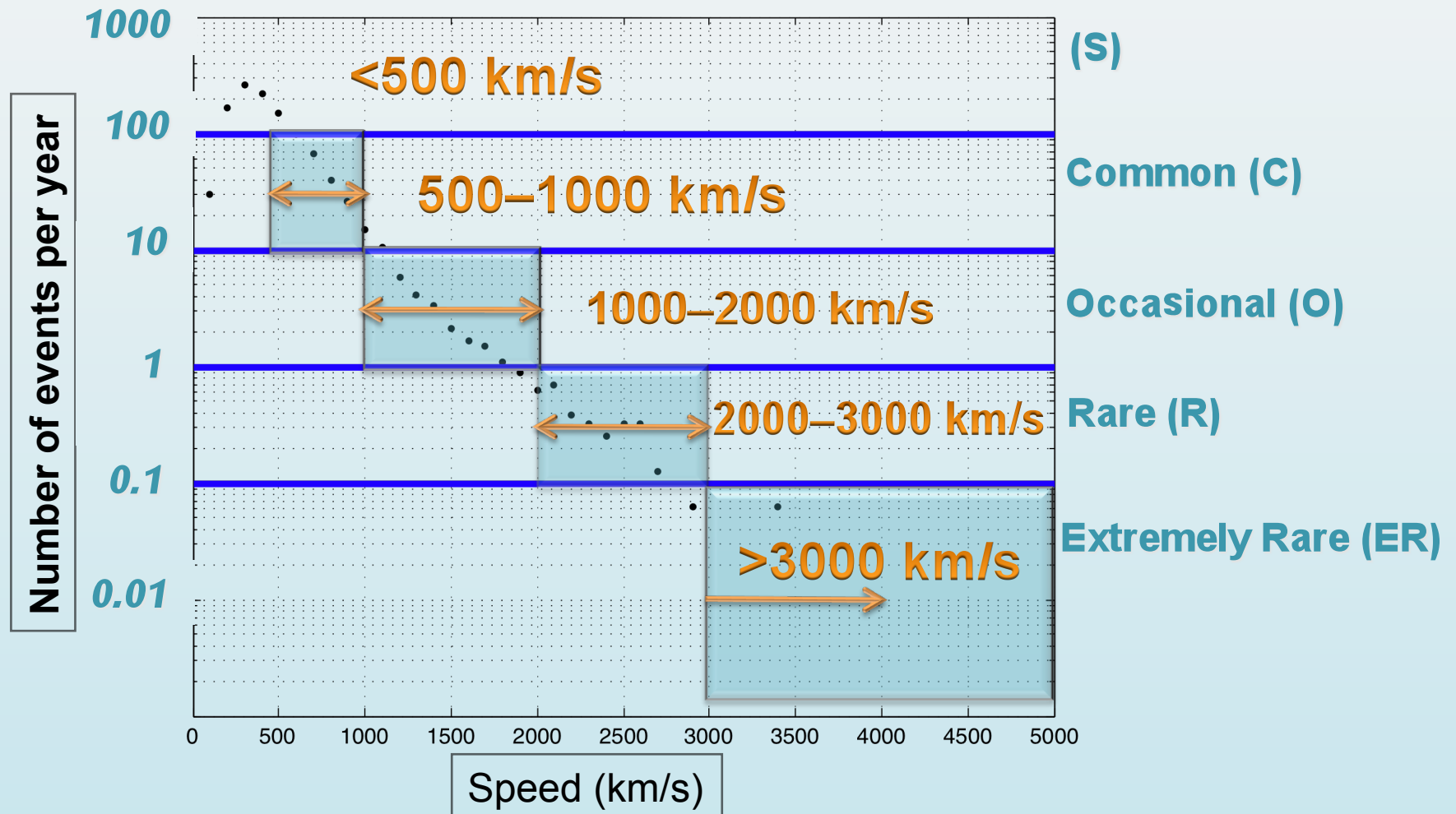


Cumulative distribution of CME speeds



(Gopalswamy et al., 2010)

NASA GSFC Space Weather Research Center CME Types (SCORE scale based on speed)

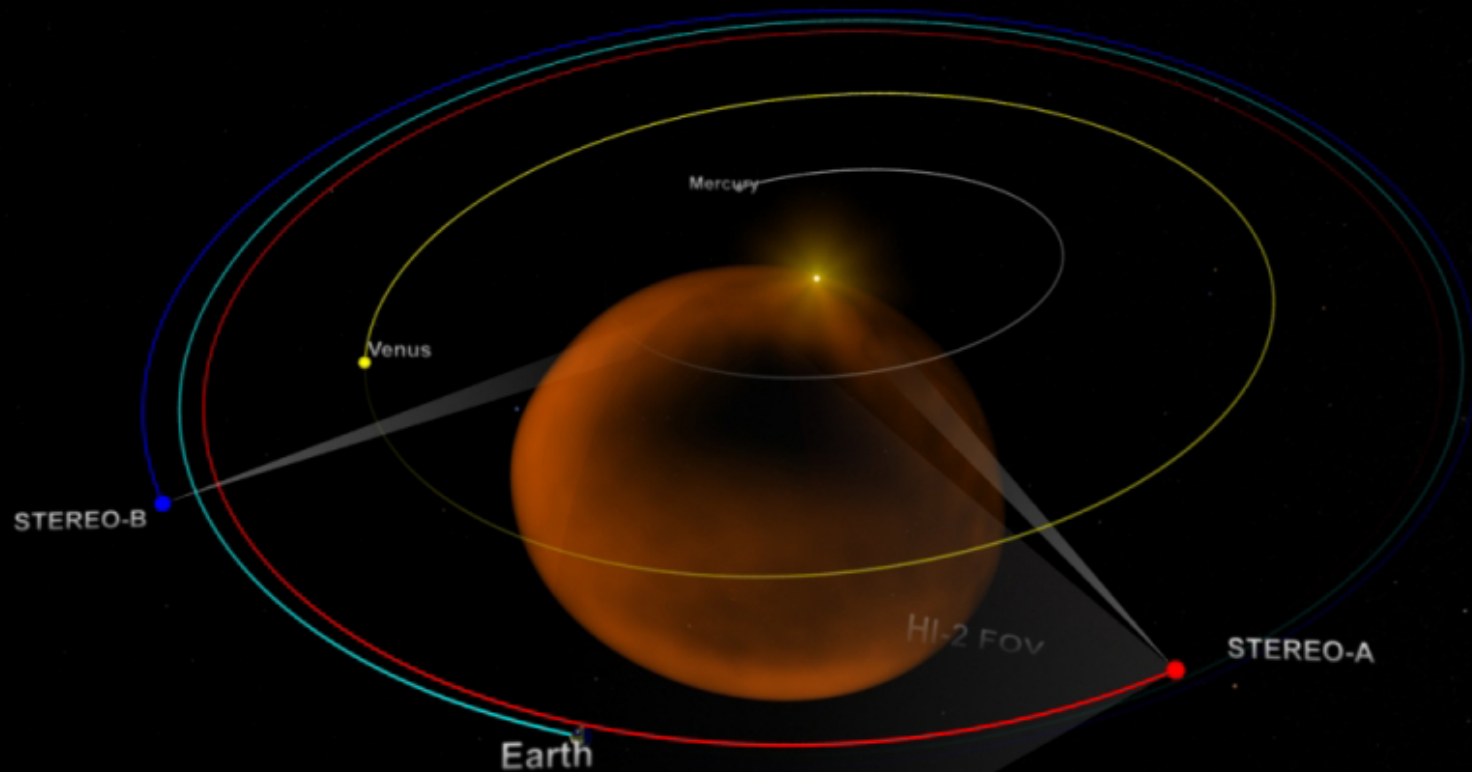


* Data: CDAWeb SOHO Lasco CME Catalog (linear speed)

The two STEREO spacecraft observe the sun from two viewpoints

View the STEREO spacecraft orbits movie:

<https://www.youtube.com/watch?v=VzhMvEkK0qA>

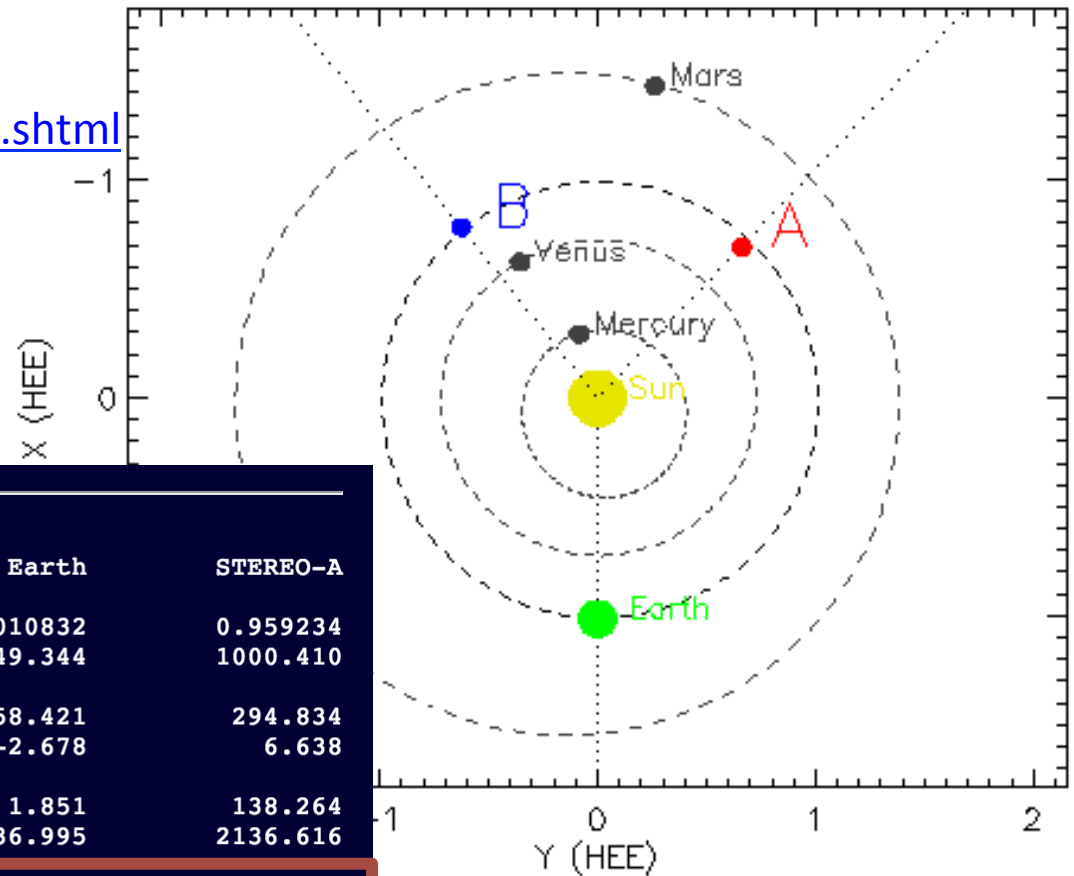


Where is STEREO?

<http://stereo-ssc.nascom.nasa.gov/where.shtml>

Click "STEREO Orbit Tool"

Longitude is measured
0 to 180° counterclockwise
0 to -180° clockwise



	STEREO-B	Earth	STEREO-A
Heliocentric distance (AU)	1.005357	1.010832	0.959234
Semidiameter (arcsec)	954.514	949.344	1000.410
HCI longitude	16.630	158.421	294.834
HCI latitude	-1.820	-2.678	6.638
Carrington longitude	220.059	1.851	138.264
Carrington rotation number	2137.389	2136.995	2136.616
Heliographic (HEEQ) longitude	-141.791	0.000	136.413
Heliographic (HEEQ) latitude	-1.820	-2.678	6.638
HAE longitude	92.490	234.029	10.422
Earth Ecliptic (HEE) longitude	-141.539	0.000	136.393
Earth Ecliptic (HEE) latitude	0.266	-0.000	0.051
Roll from ecliptic north	-0.335		0.055
Roll from solar north	6.612		3.094
Light travel time to Earth (min)	15.834	15.214	
Separation angle with Earth	141.539	136.393	
Separation angle A with B		82.067	

Date: 14 May 2013 Time: 21 : 00 UTC

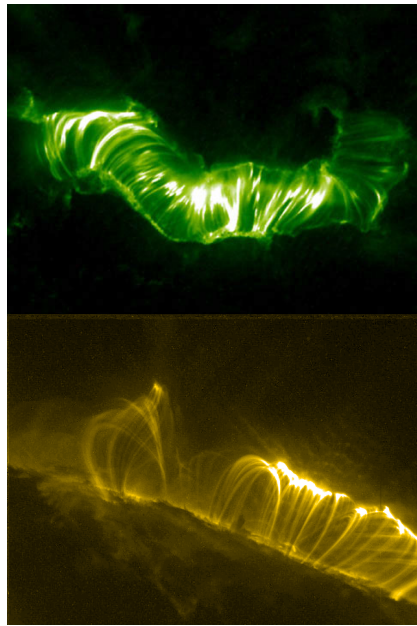
HEEQ:

Heliocentric Earth Equatorial
Z=North pole of solar rotation
axis

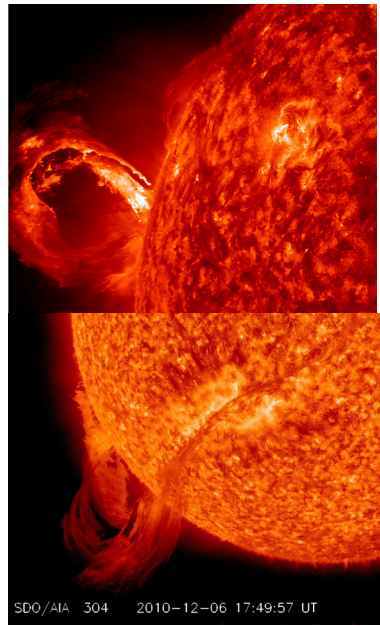
X=intersection between solar
equator and solar central
meridian as seen from Earth

CME source locations/EUV lower coronal **signatures** of CMEs

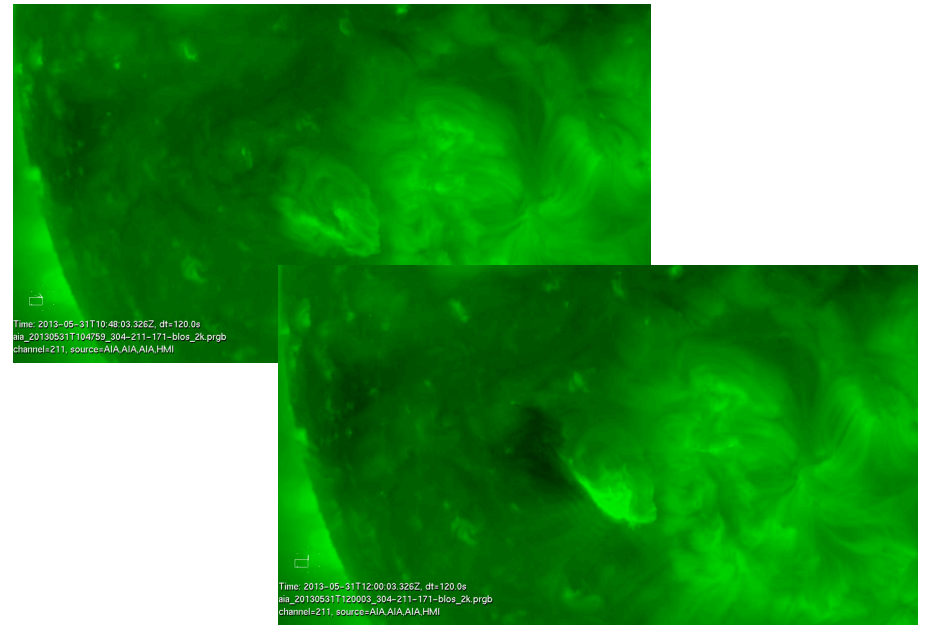
- * CMEs can originate from active regions and/or from filament eruptions.
- * Some CMEs are associated with flares.
- * EUV signatures include **post eruption arcades**, **rising loops**, **coronal dimming**, and **prominence eruptions** (click for example movies).



[post eruption arcade](#)



[prominence eruption](#)



[coronal dimmings](#)

[filament eruption](#)

Important! Always determine the source location of every CME you analyze.

This can help you decide which coronagraph combinations to choose, and assess the accuracy of the CME parameters you obtain.

[Sun Primer: Why NASA Scientists Observe the Sun in Different Wavelengths](#)

More on this topic next Thursday!

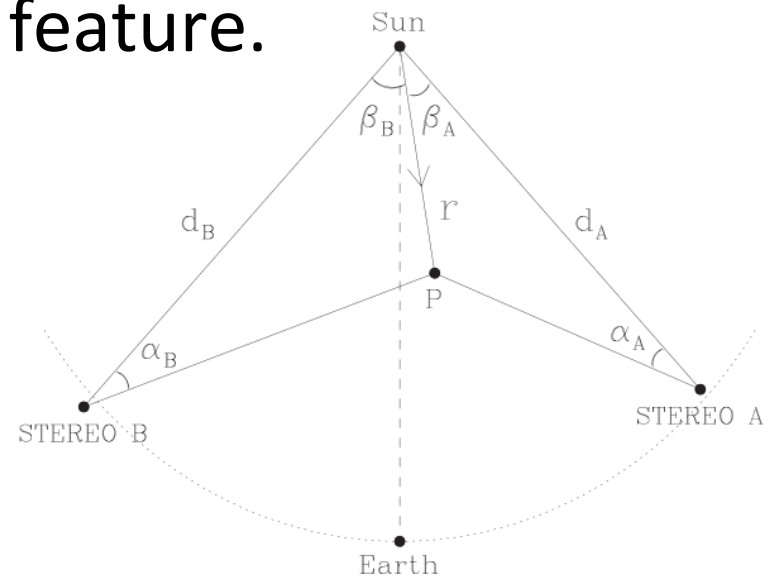
Geometric Triangulation

- Measuring the **same feature** (assumption) in two coronagraphs and using simple geometric relations to derive CME position and speed
- Observations are integrated line-of sight information through a 3D structure – projection effects, and scattering amplitudes impact the feature being measured!
- Note: StereoCAT does not use the edge locations (width) when triangulating the feature.

$$\frac{r \sin(\alpha_A + \beta_A)}{\sin \alpha_A} = d_A,$$

$$\frac{r \sin(\alpha_B + \beta_B)}{\sin \alpha_B} = d_B,$$

$$\beta_A + \beta_B = \gamma,$$



CME analysis Procedure with StereoCAT

- * Identify the CME and the [start time](#). (The CME start time is the time it is first observed by any of the four coronagraphs)
- * Observe all available coronagraph images in motion. Look for the [same](#) CME leading edge [feature](#) in various spacecraft.
- * Look at EUV images in motion near the CME start time and identify the [source location](#) and any [lower coronal signatures](#) (post eruption arcade, dimming, rising loops, filament eruption).

Go to StereoCAT: <http://ccmc.gsfc.nasa.gov/analysis/stereo/>

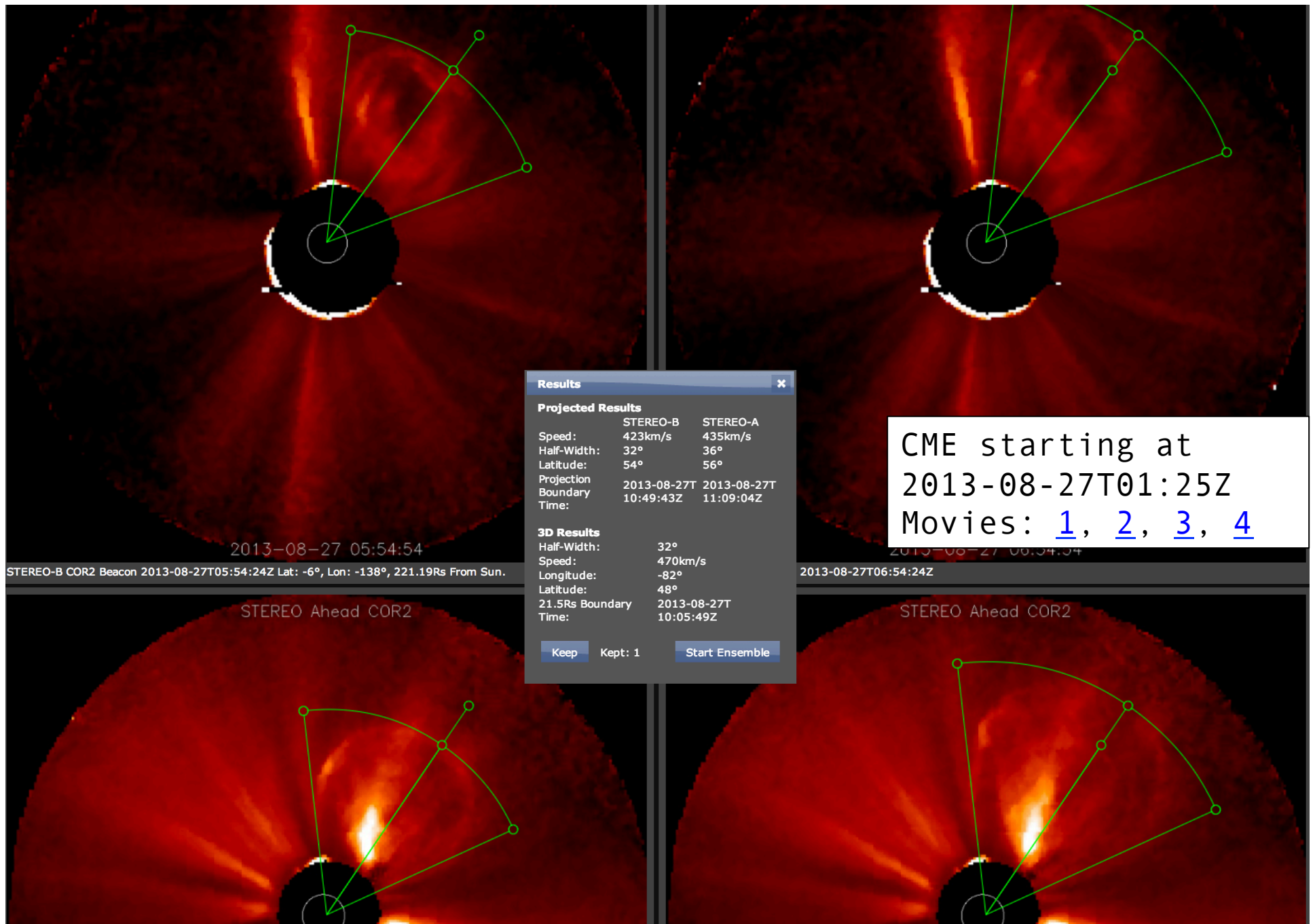
- * Select [two overlapping times](#) for each [spacecraft pair](#) available. Times should be around 45-75 minutes apart, and try to choose times just before the CME leading edge has left the field of view. It is useful to refer back to the CME movies while selecting images.
- * Perform plane of sky measurements CME leading edge and obtain triangulation results if appropriate. Determine final [CME parameters](#) (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).

Resources & iSWA layouts

- * StereoCAT: <http://ccmc.gsfc.nasa.gov/analysis/stereo/>
- * 40 Frame coronagraph and EUV movies <http://go.nasa.gov/16bTvzK>
- * Where is STEREO? <http://stereo-ssc.nascom.nasa.gov/where.shtml> and http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif
- * Solar Images with grid overlays <http://www.solarmonitor.org/>

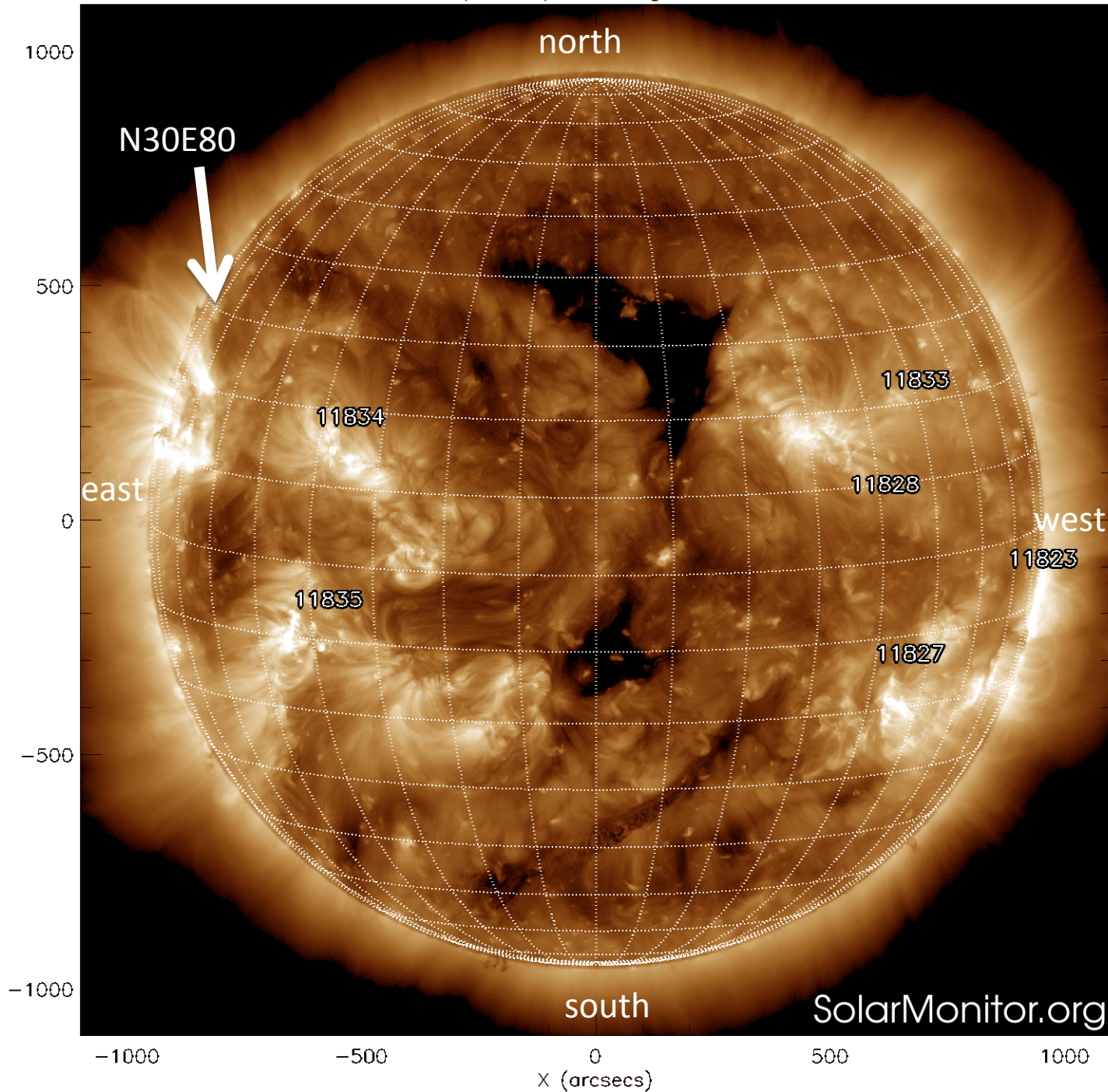
CME analysis with StereoCAT tips/notes

- * Make sure you are measuring the **same feature** in each spacecraft.
- * If you cannot see the leading edge of the CME in image (**halo**), then it is **not appropriate** to use the triangulation method. In this case, estimate the plane of sky speed. It may be cautiously used for an asymmetric halo.
- * Don't forget to determine the **source location** and **signatures**. Use these to assess the accuracy of your results (which spacecraft pairs will give the best results), or to derive the radial velocity from the plane of sky speed.
- * Measure each CME **about 10 times** with various time and spacecraft pairs to get a feel for the parameters and the measurement error.
- * The two selected times should be around **45-75 minutes apart** for each spacecraft.
- * The time between each spacecraft pair should be less than **10 minutes**.
- * Keep in mind that the goal is to determine the parameters at 21.5 Rs, not necessarily the fastest or earliest speed. Try to choose times just before the CME leading edge is closest to 21.5 Rs.
- * Bear in mind that plane of sky speeds should always be lower than the derived radial velocity.



Example of a two-timepoint measurement ([click here to see in StereoCAT](#))

SDO AIA Fe XII (193 Å) 27-Aug-2013 20:59:18.840

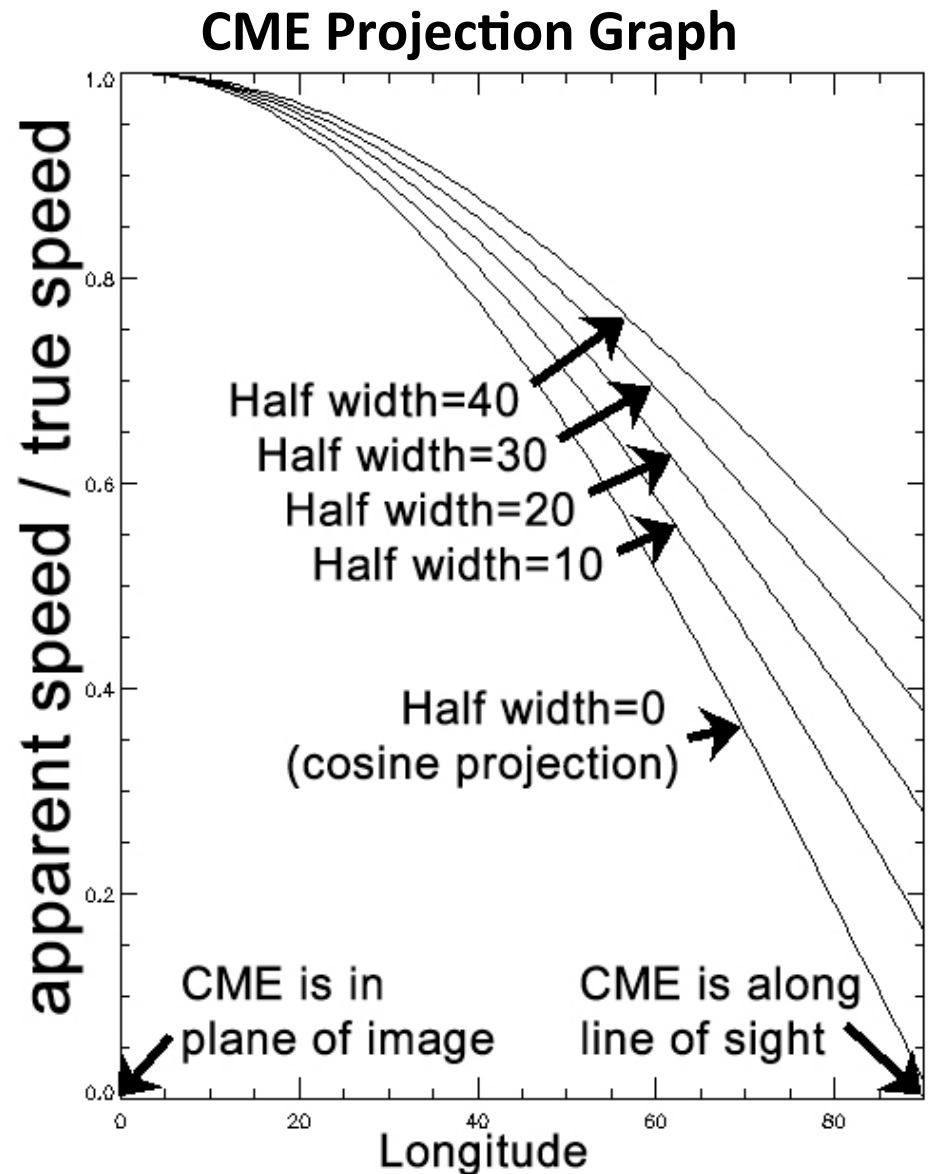


You can determine the source region coordinates using a grid overlay from solarmonitor.org or the [magnetic connectivity cygnet](#) in iSWA. (Each grid cell is 10 degrees).

Remember that east is to the left!

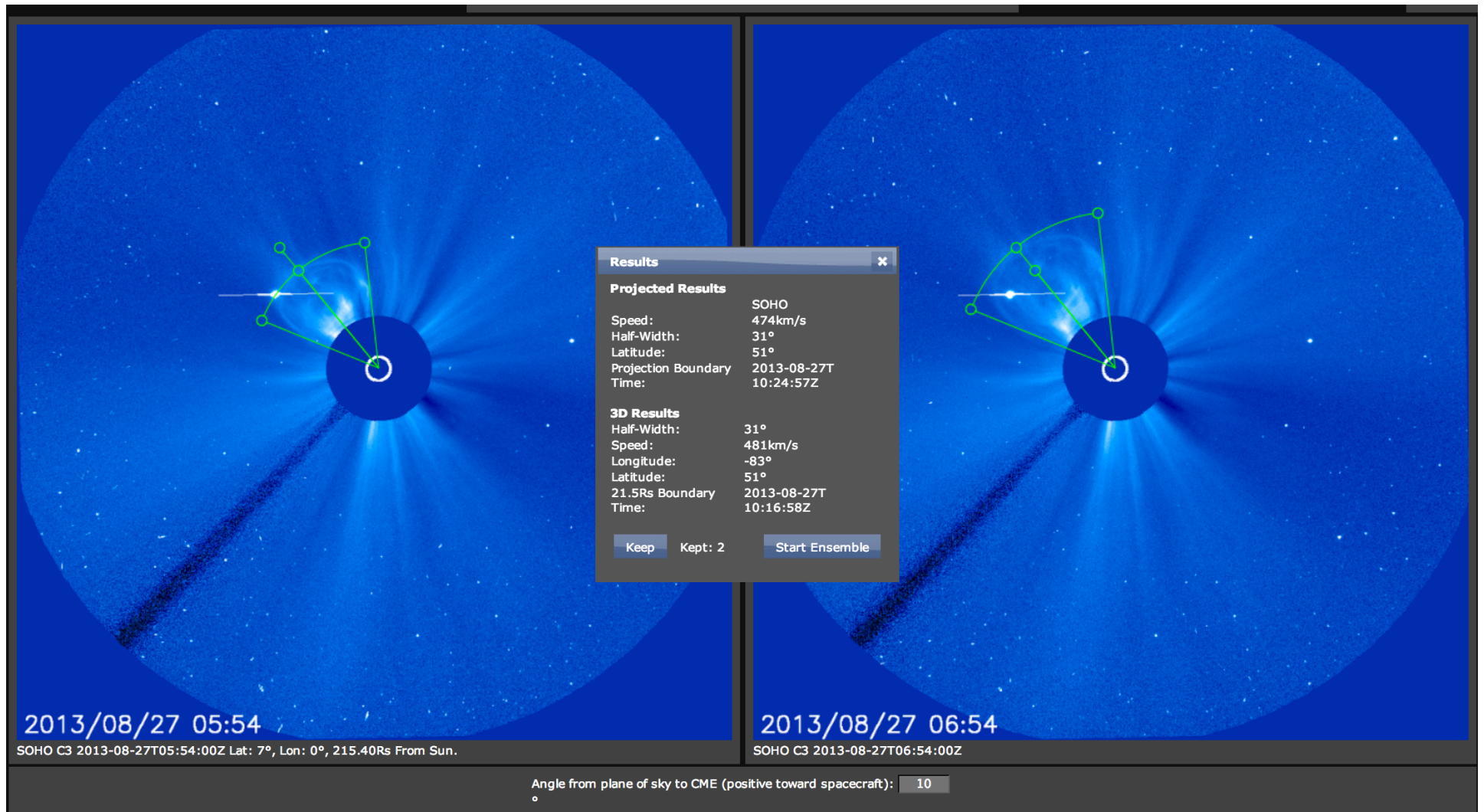
StereoCAT: Single spacecraft mode

- * If data from only one spacecraft is available, first measure the [plane of sky speed](#)
- * Use the CME [source location](#), [signatures](#) and qualitative information from other coronagraphs to determine the CME longitude
- * Using this longitude, determine the [angle the CME makes with the plane of sky](#) (positive towards observer).
- * If this angle is < 30 deg enter it at the bottom of the measurement screen, which does a simple $\cos(\theta)$ approximation.
- * If the [angle](#) compared to the plane of sky is [larger](#), or the CME is very [wide](#), use the [CME Projection Graph](#) to determine the approximate 3D speed.
 - Use your width and source longitude to look up the ratio of the plane of sky speed to the true speed on the y axis.
 - Divide your measured plane of sky speed by the ratio you looked up to obtain the true 3D speed.



[EXAMPLE in StereoCAT](#) (or next slide)

Example of a single spacecraft two-time point measurement [\(click here to see in StereoCAT\)](#)

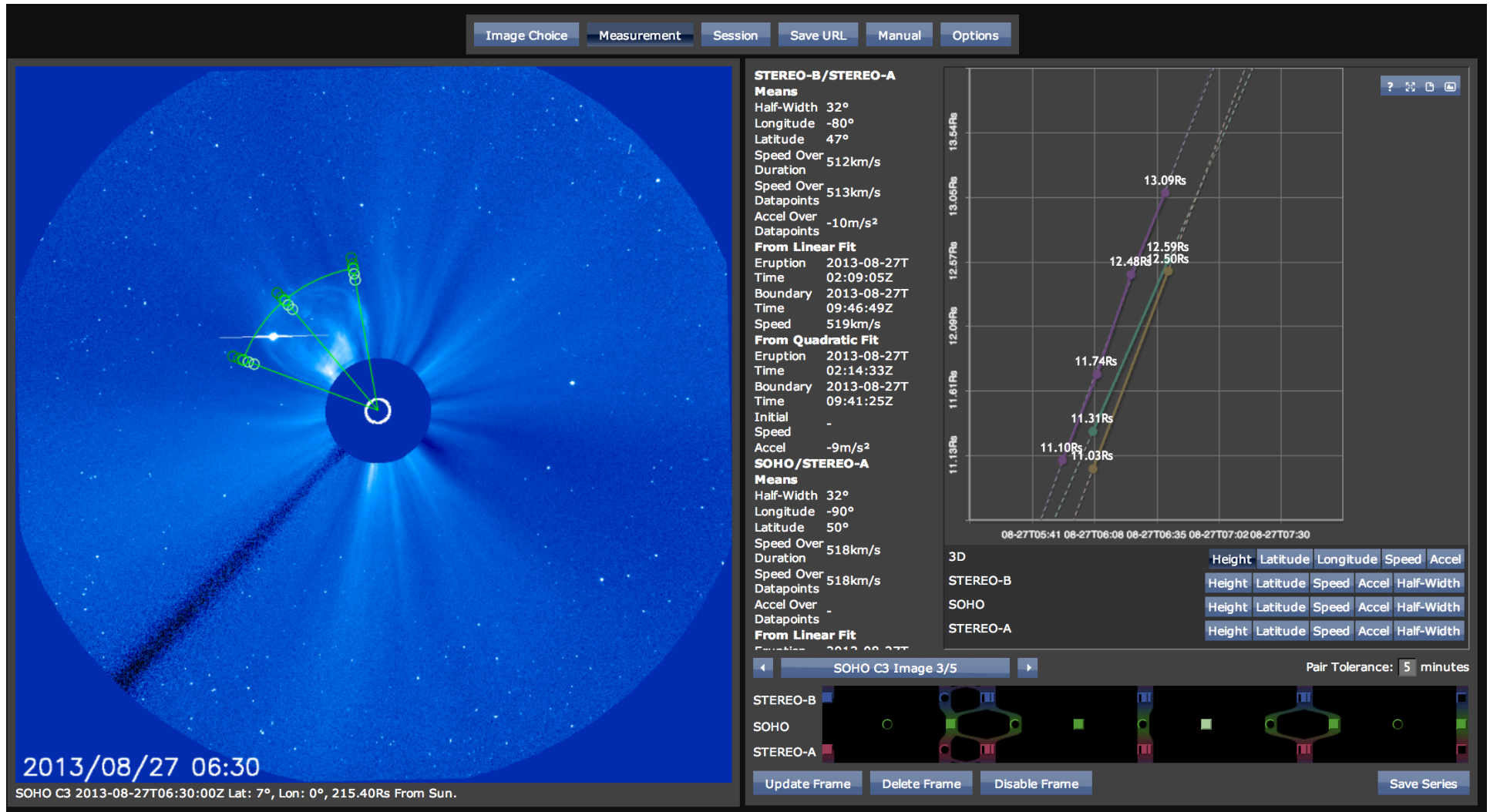


CME starting at
2013-08-27T01:25Z

Advanced Users: StereoCAT Frameseries mode

- * The same procedure and factors apply to [frameseries](#) mode. This mode allows you to measure multiple coronagraph images at once to create a [height-time plot](#), see the manual for usage details.
- * As usual, be careful about the spacecraft [pairs](#) you use. By looking at the different graphs, you can see what the plane of sky heights and triangulated heights are for each measurement. This can help you determine when the triangulation is not accurate.
- * This mode offers a [linear fit](#), [quadratic fit](#), and an [average](#) over all points. All of these results are dependent on which points you measure and how long your time range is. Be sure to carefully study [all information](#) under “Frameseries Results”, and compare to your two-timepoint measurements.

Example of frameseries measurement [\(click here to see in StereoCAT\)](#)



CME starting at
2013-08-27T01:25Z

CME Analysis Resources & iSWA layouts

- * StereoCAT: <http://ccmc.gsfc.nasa.gov/analysis/stereo/>
- * 40 Frame coronagraph and EUV movies <http://go.nasa.gov/16bTvzK>
- * Where is STEREO? <http://stereo-ssc.nascom.nasa.gov/where.shtml>
and http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where.gif
- * Solar Images with grid overlays <http://www.solarmonitor.org/>
- * <http://cdaw.gsfc.nasa.gov/movie/>

CME assignment zero (in-class workshop Tues 6/4) complete by Fri 6/6

For the CMEs listed below, follow the CME analysis procedure described in the lesson and also submit answers to the following questions for each CME:

HW#0 CMEs starting at

- 1) 2014-05-12T12:18Z
- 2) 2012-10-05T03:24Z
- 3) 2012-07-12T16:54Z
- 4) 2013-02-26T14:06Z

Resources & iSWA layouts

- * StereoCAT: <http://ccmc.gsfc.nasa.gov/analysis/stereo/>
- * 40 Frame coronagraph and EUV movies <http://go.nasa.gov/16bTvzK>
- * Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_qif
- * <http://cdaw.gsfc.nasa.gov/movie/>
- * Solar Images with grid overlays <http://www.solarmonitor.org/>

Fill out the form: <http://bit.ly/2014cme0>

- a) What is the source location for this CME? (list the location e.g. N15E20, instrument/wavelength, and time of the observation).
- b) Describe the EUV lower coronal signature for this CME (e.g. flare, post eruption arcade/loops, rising loops, dimming, filament eruption).
- c) Is the CME a halo in any of the coronagraphs? If so, is it moving away from or towards the observer?
- d) Which coronagraph instrument first observed the CME at the start time?
- e) What are your final **CME parameters** (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).
- f) Compare your EUV source location obtained in (a) with the parameters obtained in (e). Discuss why they might be different.
- g) Submit your “Save URL” of your measurements.

CME assignment one (Fri 6/6, due 6/13)

For the CMEs listed below, follow the CME analysis procedure described in the lesson and also submit answers to the following questions for each CME:

HW#1 CMEs starting at

- 1) 2013-10-22T04:36Z
- 2) 2013-11-07T00:00Z
- 3) 2013-11-07T10:39Z
- 4) 2012-07-17T14:25Z
- 5) 2013-01-13T07:24Z

Resources & iSWA layouts

- * StereoCAT: <http://ccmc.gsfc.nasa.gov/analysis/stereo/>
- * 40 Frame coronagraph and EUV movies <http://go.nasa.gov/16bTvzK>
- * Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif
- * <http://cdaw.gsfc.nasa.gov/movie/>
- * Solar Images with grid overlays <http://www.solarmonitor.org/>

Fill out the form: <http://bit.ly/2014cme1>

- a) What is the source location for this CME? (list the location e.g. N15E20, instrument/wavelength, and time of the observation).
- b) Describe the EUV lower coronal signature for this CME (e.g. flare, post eruption arcade/loops, rising loops, dimming, filament eruption).
- c) Is the CME a halo in any of the coronagraphs? If so, is it moving away from or towards the observer?
- d) Which coronagraph instrument first observed the CME at the start time?
- e) What are your final **CME parameters** (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).
- f) Compare your EUV source location obtained in (a) with the parameters obtained in (e). Discuss why they might be different.
- g) Submit your “Save URL” of your measurements.

CME assignment two (Fri 6/13)

For the CMEs listed below, follow the CME analysis procedure described in the lesson and also submit answers to the following questions for each CME. (Fill out the form: <http://bit.ly/swcme2>)

HW#2 CMEs starting at

- 1) 2013-03-15T06:54Z
- 2) 2013-04-11T07:36Z
- 3) 2012-09-28T00:12Z
- 4) 2012-09-28T10:54Z
- 5) 2013-01-21T08:48Z

Resources & iSWA layouts

- * StereoCAT: <http://ccmc.gsfc.nasa.gov/analysis/stereo/>
- * 40 Frame coronagraph and EUV movies <http://go.nasa.gov/16bTvzK>
- * Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif
- * <http://cdaw.gsfc.nasa.gov/movie/>
- * Solar Images with grid overlays <http://www.solarmonitor.org/>

Part 1: a) What is the source location for this CME? (list the location e.g. N15E20, instrument/wavelength, and time of the observation).

b) Describe the EUV lower coronal signature for this CME (e.g. flare, post eruption arcade/loops, rising loops, dimming, filament eruption).

c) Is the CME a halo in any of the coronagraphs? If so, is it moving away from or towards the observer?

d) Which coronagraph instrument first observed the CME at the start time?

e) What are your final **CME parameters** (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).

f) Compare your EUV source location obtained in (a) with the parameters obtained in (e). Discuss why they might be different.

g) Submit your "Save URL" of your measurements.

Part 2: Reanalyze the CMEs above using single spacecraft mode and the CME Projection Graph:

h) Single Spacecraft mode: for both spacecraft chosen in Part 1 use your longitude derived in (e) to determine the "angle from plane of the sky" for each measurement. Use this in single spacecraft mode to get the 3D speed.

i) Now use the CME projection graph with your width and your 3D longitude from (e) to derive two estimates of the 3D speed for each spacecraft viewpoint.

j) Now do the same (j), only using the source longitude from (a) instead of the longitude from (e).

k) You now have determined the 3D speed with several different methods. How much do they match? Why are there differences?

Summary of CME Assignments

CME Assignment Instructions:

For the CMEs listed below, follow the CME analysis procedure described in the lesson and also submit answers to the following questions for each CME (fill out the forms):

- What is the source location for this CME? (list the location e.g. N15E20, instrument/wavelength, and time of the observation).
- Describe the EUV lower coronal signature for this CME (e.g. flare, post eruption arcade/loops, rising loops, dimming, filament eruption).
- Is the CME a halo in any of the coronagraphs? If so, is it moving away from or towards the observer?
- Which coronagraph instrument first observed the CME at the start time?
- What are your final **CME parameters** (radial speed, half width, longitude, latitude, and time at 21.5 Rs (solar radii)).
- Submit your "Save URL" of your measurements.

Note: HW#2 has extra steps

Resources & iSWA layouts

- * StereoCAT: <http://ccmc.gsfc.nasa.gov/analysis/stereo/>
- * 40 Frame coronagraph and EUV movies <http://go.nasa.gov/16bTvzK>
- * Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif
- * <http://cdaw.gsfc.nasa.gov/movie/>
- * Solar Images with grid overlays <http://www.solarmonitor.org/>

Assignment forms:

<http://bit.ly/2014cme0>

<http://bit.ly/2014cme1>

<http://bit.ly/2014cme2>

Due 6/6 Fri morning

HW#0 CMEs starting at

- 1) 2014-05-12T12:18Z
- 2) 2012-10-05T03:24Z
- 3) 2012-07-12T16:54Z
- 4) 2013-02-26T14:06Z

Due 6/13 Fri morning

HW#1 CMEs starting at

- 1) 2013-10-22T04:36Z
- 2) 2013-11-07T00:00Z
- 3) 2013-11-07T10:39Z
- 4) 2012-07-17T14:25Z
- 5) 2013-01-13T07:24Z

Due 6/13 Fri afternoon

HW#2 CMEs starting at

- 1) 2013-03-15T06:54Z
- 2) 2013-04-11T07:36Z
- 3) 2012-09-28T00:12Z
- 4) 2012-09-28T10:54Z
- 5) 2013-01-21T08:48Z

HW#2 is optional, except forecasting interns

StereoCAT tips

- * Preferred browser is chrome.
- * See the [StereoCAT manual](#): explains the GUI and more options.
- * Handy keyboard shortcuts are listed at the end of the manual
- * If your measurement is not centered on the LASCO image (because LASCO rolls a few times a year), click on “Options”, then “Enable Sun Point Handles”, then “Okay”. Now you can center the measurement correctly.
- * To see where the CME projection is relative to 21.5Rs in LASCO, click on “Options”, then “Enable Boundary Rings”, then “Okay”.
- * If images are not loading in StereoCAT, try changing the server. Click on “Options”, in the server box it says “iswa.ccmc.gsfc.nasa.gov”. You can try changing this to “iswa.gsfc.nasa.gov”, “iswa3.gsfc.nasa.gov”, “iswax.ccmc.gsfc.nasa.gov”. Click okay, then search again for the date/times.
- * Remember to click “save series” when you are done with your frameseries measurements, clicking away from this screen will lose them.

Slide link summary

SW REDI website

<http://ccmc.gsfc.nasa.gov/support/SWREDI/swredi.php>

iSWA <http://iswa.gsfc.nasa.gov>

iSWA Cygnet Glossary http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Full_iSWA_Cygnet_List

iSWA Space Weather Glossary <http://iswa3.ccmc.gsfc.nasa.gov/wiki/index.php/Glossary>

Example CME movie

http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=stb_cor2&img2=sta_cor2&stime=20120712_1500&etime=20120712_2000

<http://helioviewer.org/?movieId=zZv95> <http://helioviewer.org/?movieId=tZv95>

Helioviewer solar visualization tool <http://www.helioviewer.org/>

SOHO LASCO CME Catalog http://cdaw.gsfc.nasa.gov/CME_list/

SWRC SCORE CME scale <http://swrc.gsfc.nasa.gov/main/score>

STEREO orbit movie <https://www.youtube.com/watch?v=VzhMvEkK0gA>

Sun Primer: Why NASA Scientists Observe the Sun in Different Wavelengths

http://www.nasa.gov/mission_pages/sunearth/news/light-wavelengths.html

EUV lower coronal signatures of CMEs movies

post eruption arcade

http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=sta_e195&img2=sta_cor2&stime=20130526_1500&etime=20130527_0000

prominence eruptions <http://go.nasa.gov/19Dni3v>

http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=lasc2rdf&img2=sdo_a304&stime=20130430_2200&etime=20130501_0800

filament eruptions <http://go.nasa.gov/12qcWDO>

http://www.lmsal.com/hek/gallery/podimages/2013/06/01/pod_malanushenko_anna_2013-06-01T02:24:03.851/anny_AIA-304_20130531T113203-20130531T185203_120s_made_20130601T022253_720p.mpg

coronal dimmings

http://www.lmsal.com/hek/gallery/podimages/2013/06/01/pod_malanushenko_anna_2013-06-01T00:52:07.870/anny_AIA-211_20130531T094003-20130531T145203_120s_made_20130601T005102_720p.mpg

http://cdaw.gsfc.nasa.gov/movie/make_javamovie.php?img1=stb_cor2&img2=stb_e195&stime=20120527_0300&etime=20120527_1600

Resources & iSWA layouts

* CME analysis tool: <http://ccmc.gsfc.nasa.gov/analysis/stereo/>

* 40 Frame coronagraph and EUV movies <http://go.nasa.gov/16bTvzK>

* Where is STEREO? http://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif

* <http://cdaw.gsfc.nasa.gov/movie/>

* Solar Images with grid overlays <http://www.solarmonitor.org/>